DESIGN AND DEVELOPMENT OF AN IMPELLER WIND TURBINE

by

AHMED YOUNUS QASIM
(1041410449)

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DECLARATION OF THESIS

Author's full name ... AHMED YOUNUS QASIM.............

Date of birth ... 18th / OCTOBER / 1966....…………....

Title**:** Design and development of an impeller wind turbine

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LIST OF SYMBOLS, ABBREVIATIONS

Symbol	Description	Unit
A	Area	m^2
A_s	Swept area	m^2
B	Blade area	m^2
b	Width of blade	m
C	Blade length	m
Cp	Power coefficient	
Ct	Torque coefficient	
CD	Drag coefficient	kg/s
D	Turbine diameter or width of the wind turbine	m
E	Kinetic energy	m^2/s^2
Fa	Axial force	kg/s
F_D	Drag force	N
h	High of the swept area (Impeller)	m
i	Gear speed ratio	
K	Turbulent kinetic energy	
n	Number of frame	
N	Number of rotate	
Nb	Gear box efficiency	

Ng	Generator efficiency	
P	Pressure	N/m^2
ΔP	Pressure different	N/m^2
r	Impeller radius	m
Re	Reynolds number	
R	Force radius	m
T	Torque	N.m
t	Thickness	m
u	Blade velocity	m/s
V	Wind velocity	m/s
W_{gen}	Power produce by generator of turbine	W
W_{wind}	Power produce by wind turbine	W
W_m	Mechanical power	W
W	power	W
Z	Vane width	M
β	Shadow angle	deg

LIST OF NUMENCLATURE

γ	Angle of frame position	Deg
θ	Angle between frames	deg
Ψ	Vanes frame angle	deg
λ	Tip speed ratio	
σ	Solidity	
$\dot{m}$	Mass flow rate	Kg/s
μ	Kinetic viscosity	$N.s/m^2$
ρ	Density	kg/m^3
ω	Angular velocity of the rotating turbine	rad/s
η	Wind turbine efficiency	
α	Beginning of wind shadow angle for second frame	deg
α_1	Beginning of wind shadow angle for first frame	deg

Reka bentuk dan pembangunan turbin angin pendesak

ABSTRAK

Dalam bidang reka bentuk turbin angin, masih terdapat skop penambahbaikan. Hari ini, tenaga angin - terutamanya oleh turbin skru angin - menghasilkan kurang daripada 1.0% daripada jumlah tenaga yang digunakan di seluruh dunia. Hampir, kecekapan standard tiga bilah turbin skru angin adalah sekitar 30%. Ini jenis turbin adalah berdasarkan daya angkat angin pada turbin berputar. Ini turbin agak mahal kerana bentuk aerodinamik yang kompleks pisau yang diperbuat daripada bahan komposit. A paksi menegak turbin angin boleh direka dengan nilai yang tinggi faktor seretan. Kerja-kerja ini berkaitan dengan reka bentuk jenis pendesak paksi menegak turbin angin baru, yang menggunakan tenaga angin dengan lebih berkesan. Reka bentuk ini membentangkan reka bentuk bingkai khas dengan bilah. Turbin angin bingkai direka untuk meningkatkan pengeluaran turbin angin yang menggunakan tenaga kinetik angin. Lima model yang berbeza daripada paksi menegak turbin angin yang direka dan diuji dalam terowong angin dalam kerja-kerja ini. Mereka adalah tiga frame alih ram bentuk rongga, tiga frame alih ram bentuk rongga dengan gear penguat, tiga tetap frame bentuk rongga ram, empat bingkai alih ram bentuk rongga dan tiga rangka alih ram bentuk plat rata. Ram yang terletak di bar menegak dipasang di bergantung daripada bingkai. Seperti reka bentuk yang membolehkan putaran bar dengan bingkai di bawah tindakan tenaga angin serentak pada satu arah dan bebas pada arah yang lain. Bingkai yang berkaitan dengan batang, di mana satu hujung adalah berkaitan dengan penjana elektrik. Bingkai direka dengan kecenderungan sudut bilah yang mewujudkan rongga apabila ram ditutup. Di sisi lain pendesak, apabila ram alih yang terbuka, dan kerangka adalah di bawah tindakan angin, udara pas bebas melalui bingkai, dan mengurangkan tork negatif. Dalam semua model menggunakan bilah berbentuk rongga, 45 ° sudut ram digunakan. Keputusan dibentangkan dalam bentuk pekali seretan, pekali kuasa, nisbah kelajuan tip untuk halaju angin berbeza-beza dari 5 m / s hingga 17 m / sec. Ia didapati bahawa tiga frame alih ram rongga model bentuk mempunyai pekali kuasa maksimum (Cpmax) 0.32 pada kelajuan 8 m / s dan hujung nisbah kelajuan angin 0.31. Semua model lain memberikan nilai Cpmax lebih rendah daripada nilai ini untuk julat yang sama halaju angin. Baru yang dicadangkan pendesak jenis menegak paksi turbin angin boleh digunakan di seluruh dunia kerana kecekapan yang tinggi, pembinaan mudah, dan teknologi mudah. Di samping itu, turbin angin yang dicadangkan juga boleh dibuat daripada bahan-bahan murah.

Design and development of an impeller wind turbine

ABSTRACT

In the area of wind turbine design, there is still scope of improvement. Today, wind energy - mainly by wind screw turbines - produces less than 1.0% of the total energy used worldwide. Practically, the efficiency of the standard three-blade wind screw turbines is around 30%. This type of turbine is based on the wind lift force on rotating turbine. These turbines are quite expensive due to the complex aerodynamic shape of blades that are made of composite materials. A vertical axis wind turbine can be designed with high value of the drag factor. The present work relates to the design of a new impeller type vertical axis wind turbine, which is uses wind energy more effectively. This design presents a special frame design with vanes. The frame wind turbine is designed to increase the output of a wind turbine that uses kinetic energy of the wind. Five different models of the vertical axis wind turbine are fabricated and tested in a wind tunnel in the present work. They are three frame movable vane cavity shape, three frame movable vane cavity shape with amplifier gear, three frame fixed vane cavity shape, four frame movable vane cavity shape and three frame movable vane flat plate shape. The vanes are located on vertical bars installed in hinges of the frames. Such a design enables the rotation of the bars with frames under the action of wind force simultaneously at one direction and independently at other directions. The frames are connected with the shaft, of which one end is connected with the electric generator. The frames are designed with angular inclinations of vanes that create cavities when vanes are closed. On the other side of the impeller, when the movable vanes are open, and the frame is under wind action, the air passes freely through the frame, and decreases the negative torque. In all the models using cavity shaped vanes, 45˚vane angle is used.The results are presented in the form of drag coefficient, power coefficient, tip speed ratio for wind velocities varying from 5 m/sec to 17 m/sec. It is found that a three-frame movable vane cavity shape model has a maximum power coefficient (Cp_{max}) of 0.32 at a wind velocity 8 m/s and tip speed ratio 0.31. All other models give the values of Cp_{max} lower than this value for the same range of wind velocity. The proposed new impeller type vertical axis wind turbine can be used worldwide due to its high efficiency, simple construction, and simple technology. Further, the proposed wind turbine can also be made from cheap materials.

CHAPTER 1

INTRODUCTION

1.1 Background

The power from the wind will never cease while the sun is still rising and the earth is revolving. Wind exists everywhere on the earth, and in some places with considerable energy density. This thesis aims to study this renewable energy, which will remain a useful power source until the end of this world. Wind has been used in the past to generate mechanical power. Nowadays wind power has become a promising source to generate electricity because it is clean, quiet and efficient. It reduces acid rain, smog and pollutants to the atmosphere. Renewable energy has become popular in recent years, due to the need for the utilization of more environmentally friendly energy sources. In generating wind power, both the vertical axis wind turbines (VAWTs) and the horizontal axis wind turbines (HAWTs) play significant roles.

Wind power is the conversion of wind kinetic energy into a useful form, such as mechanical or electrical energy that can be harnessed for practical use by using wind turbines. Wind energy is one of the cheapest and cleanest of the renewable energy technologies than all other known ones. The potential energy created by wind power is plentiful, and reduces greenhouse gas emissions when it displaces fossil fuel derived electricity. Wind turbine technology has lately been steadily improved.

1.2 Wind energy

When the earth is irradiated by the sun, the ground absorbs some of this radiation. This heated ground warms the air above it. Hot air rises in what are called convection currents. The uneven heating of the earth's surface causes winds. For example, if the sun's rays fall on land and sea, the land heats up more quickly. This results in the air above the land moving upwards more quickly than that over the sea, (hot air rises). As a result the colder air over the sea will rush in to fill the gap left by the rising air. This process gives rise to high and low pressure areas, and thus to winds.

Wind energy is non-polluting and is freely available in many areas. Wind turbines are becoming more efficient, making the cost of the electricity generation to fall. Large balancing areas and aggregation benefits of large areas help to reduce the variability and forecast errors of wind power as well as in pooling more cost effective balancing resources (Holttinen et al. 2009). There are already several power systems and control areas coping with large amounts of wind power (Saoder et al. 2007). Denmark, Germany, Spain, Portugal and Ireland have integrated 9-20 % of wind energy (of yearly electricity demand). However, the disadvantages of wind energy exist as well. To be efficient, wind turbines need to be linked together in wind farms, often with 20 turbines or more. This looks unsightly, and can be noisy. The wind farms also need to be sited reasonably close to populations so that the electricity generated can be distributed. Another disadvantage is that winds are intermittent and do not blow all the time. In this thesis, one turbine used to convert wind energy is optimized in order to improve the output power.

1.3 Type of wind turbine

There are many concepts to classify the types of wind turbine which are used. All of the wind turbines fall into two types, depending on whether the turbine blade rotates about a horizontal axis or a vertical axis as shown in Figure (1.1).

1.3.1 The horizontal axis wind turbine (HAWTs)

The favored form of turbines used for electricity generation purposes is the horizontal axis wind turbine (HAWT) with low solidity ratio (ratio of blade area to swept area) and high tip speed ratio. This type of turbine has a high efficiency or power coefficient, but relatively low torque. By contrast, the traditional "American Windmill" or "Southern Cross", used throughout Australia and the USA for water pumping purposes, is a high solidity, low tip speed ratio device that produces a high torque suitable for direct drive of relatively simple mechanical pump systems. The HAWTs have a maximum theoretical power coefficient of approximately 0.45. However, in reality this wind turbine can only achieve an average power coefficient of approximately of 0.3 (Usubamatove et al. 2010). Figure (1.1) shows the main components of modem propeller type HAWTs. The main advantage of this machine is its high power coefficient compared to the other types. Nevertheless, the disadvantages of HAWTs include their operation at high starting wind velocity, low starting torque, the requirement of a yaw mechanism to turn the rotor toward the wind and the power loss when the rotors are tracking the wind directions. These are the problems of the HAWTs, which are difficult to solve.

1.3.2 Vertical axis wind turbine (VAWTs)

The second major groups of wind turbine types are the vertical axis wind turbines (VAWTs). A wide variety of VAWT configurations have been proposed, dating from the Persian VAWTs used for milling grain over thousands of years ago, through to the Darrieus turbine, invented in 1926 by Georges Darrieus, which has been used extensively for power generation. One of the largest turbines ever built was the 96 m high 64 m diameter Éole Darrieus built in Canada, with a rated power output of 3.8 MW and a rotor weighing 100 tones. Other VAWT configurations include the Savonius VAWT, which is popular because of the simplicity of manufacture, as well as the straight-bladed VAWTs. The straight-bladed VAWT includes the Musgrove turbine, which led to the successful testing of a 500 kW device at Carmarthen Bay, UK (Peace, 2004).

There are many variants of the vertical axial Darrieus and Savonius turbines design, as well as a number of other similar devices under development Figure (1.1). The propeller type turbine is most commonly used in large-scale applications constituting nearly all of the turbines in the global market, while the vertical axis turbines are more commonly implemented in medium and small-scale installations. This type of wind turbine is the main focus of this research, whereby the rotor of the wind turbine rotates perpendicular to the direction of the wind.

Although VAWTs can capture ground-level winds, just like any turbine installed on a short tower, ground-level winds are subject to friction. This slows wind down as it sweeps across the land. Both friction drag and turbulence in lower-level winds around buildings and trees decrease the power available to a turbine mounted at ground level, resulting in very little extractable energy in them. The lower the wind speed, the less electricity a turbine will produce.